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Fixed Transmission Media

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1. Introduction

For successful understanding of the signal transmission in access networks that utilized fixed transmission media, it is necessary exactly to recognize essential negative influences in the real environment of metallic homogeneous symmetric lines, power distribution cables and optical fibers. This chapter discusses features and frequency characteristics of negative influences on signals transmitted by means of the VDSL technology, the PLC technology and PON networks. For the expansion of communication systems on fixed transmission media, it is necessary to have a detailed knowledge of their transmission environments and negative influences in the real developing of customer installations.

A main attention of the metallic transmission media's parts is focused on the description of the proposed VDSL and PLC simulation models and on the explanation of simulation methods for substantial negative influences. Presented simulation models represent a reach enough knowledgebase for the extended digital signal processing techniques of the VDSL and PLC signal transmissions that can be extremely helpful for various tests and performance comparisons.

A main attention of the optical transmission media's part is focused on the description of the proposed optical fiber's simulation model and on the explanation of simulation methods for its substantial linear effects - transmission factors. The presented simulation model represents a reach enough knowledgebase that can be helpful for various tests and performance comparisons of various novel modulation techniques suggested and intended to be used at signal transmissions in the transmission environment of optical fibers.

2. The environment of metallic homogeneous lines

2.1 Linear negative influences on transmitted signals

Propagation loss and linear distortions (distortions of the module and the phase characteristics and the group delay characteristic) are linear negative influences dependent on physical and constructional parameters, such as a line length, a core diameter of the wire, a mismatch of impedances in cross-connecting points of sections, a frequency bandwidth and so forth (Róka, 2004).

We first discuss the propagation loss L_{dB} in a perfectly terminated line. If R, L, G and C are primary constants of the line and $\omega = 2.\pi.f$, where f is the frequency, then

$$\gamma(\omega)=\alpha(\omega)+j.\beta(\omega)=\sqrt{(R+j.\omega.L).(G+j.\omega.C)} \tag{1}$$

and

$$\mathcal{Z}(\omega)=\sqrt{\frac{(R+j.\omega.L)}{(G+j.\omega.C)}} \tag{2}$$

where $\gamma(\omega)$ denotes the propagation constant of the line, $\alpha(\omega)$ is the specific constant of the attenuation, $\beta(\omega)$ is the specific constant of the phase shift and $\mathcal{Z}(\omega)$ is the characteristic impedance of the line. For a perfectly terminated line with the length l, the transfer function $\mathcal{H}(l, f)$ of metallic homogeneous symmetric lines is given by

$$\mathcal{H}(l,f)=e^{-l.\gamma(f)}=e^{-l.\alpha(f)}.e^{-j.l.\beta(f)} \tag{3}$$

and the propagation loss L_{dB} is given as

$$L_{dB}(l,f)=-20.\log_{10}\left|\mathcal{H}(l,f)\right|=\frac{20}{\ln 10}.l.\alpha(f)=a_{line}(l,f)\ [dB] \tag{4}$$

We must place emphasis on the interchangeable use of terms - the line attenuation $a_{line}(l, f)$ and the propagation loss $L_{dB}(l, f)$ to designate the quantity in (4) only for the case of a perfectly terminated line. We can see that a dependency of the propagation loss L_{dB} on the line length l is linear and is also an increasing function of the frequency f as should be apparent from the expression for the propagation constant $\gamma(\omega)$ in (1). A power level of transmitted signals is also influenced by other important parameters - a diameter and constructional material of the core.

For lower frequency regions, for which $\omega.L << R$ is valid and G can be neglected, the propagation constant expressed in (1) can be simplified to

$$\gamma(\omega)\approx\sqrt{\frac{\omega.R.C}{2}}.\left[1-\frac{\omega.L}{2.R}\right]+j.\sqrt{\frac{\omega.R.C}{2}}.\left[1+\frac{\omega.L}{2.R}\right] \tag{5}$$

For frequencies less than 20 kHz, both the real and imaginary parts $\alpha(\omega)$ and $\beta(\omega)$ are approximately proportional to $\sqrt{f}$. At higher frequencies, frequency dependencies of the primary constants R and L (except for C) become noticeable and the propagation constant in (1) can be approximated by

$$\gamma(\omega)\approx\frac{R(\omega)}{2}.\sqrt{\frac{C}{L(\omega)}}+j.\omega.\sqrt{C.L(\omega)} \tag{6}$$

In this case, the imaginary part $\beta(\omega)$ is approximately a linear function of the frequency. Major variations for the real part $\alpha(\omega)$ are due to the frequency dependency of R, which becomes proportional to $\sqrt{f}$. because of the skin effect. Therefore, it is necessary to take into account increased signal attenuation in the area of higher frequencies.

The phase τ_ϕ and envelope τ_e delays of the line can be expressed as following

$$\tau_\phi(\omega) = \sqrt{\frac{\beta(\omega)}{\omega}} \qquad \tau_e(\omega) = \sqrt{\frac{d\beta(\omega)}{d\omega}} \tag{7}$$

At higher frequencies, the group envelope delay τ_e and the phase delay τ_ϕ are approximately frequency-independent and equal to the value about $\tau_e \approx \tau_\phi = 5{,}4$ μs/km.

2.2 Near-end and far-end crosstalk signals

The term "crosstalk" generally refers to the interference that enters a communication channel through some coupling paths. On Fig. 1, a kind of generating and propagating of two crosstalk types in a multipair cable is presented.

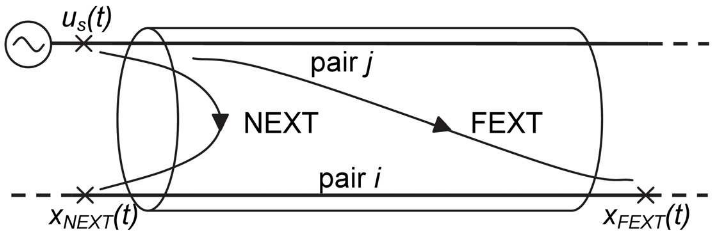

Fig. 1. Types of crosstalks in the environment of metallic homogeneous lines

At the input of pair j, the information signal $u_s(t)$ is generated. This signal, when propagating through the line, can generate two types of crosstalk signals arising in pair i. A crosstalk signal $x_{NEXT}(t)$ is called the near-end crosstalk NEXT. A crosstalk signal $x_{FEXT}(t)$ is called the far-end crosstalk FEXT. From a data communication point of view, the NEXT crosstalk is generally more damaging than the FEXT crosstalk, because the NEXT does not necessarily propagate through the line length and thus does not experience a propagation loss of the signal (Werner, 1991).

If either single or multiple interferers generate a crosstalk signal, we can define a gain of the NEXT crosstalk path according to (Werner, 1991), (Róka, 2002, 2004) using a following relation

$$\left|\mathcal{H}_{NEXT}(l,f)\right|^2 = \frac{\pi^2 . f^2 . k_{NEXT}}{\alpha(f)}\left[1 - e^{-4.\alpha(f).l}\right] \approx K_{NEXT} \cdot f^{3/2} \tag{8}$$

where variables are given as $K_{NEXT} = 0{,}882.10^{-14}.N_d^{0,6}$, N_d is the number of disturbing pairs (disturbers), f is the frequency in Hz. An approximation on the right in (8) is valid when the line length l is large and for frequency regions where the real part $\alpha(\omega)$ of the propagation constant is proportional to $\sqrt{f}$. We can also derive a gain of the FEXT crosstalk path in a similar manner using a following relation

$$\left|\mathcal{H}_{FEXT}(l,f)\right|^2 = 4.\pi^2.f^2.k_{FEXT}.l.e^{-2.\alpha(f).l} \approx K_{FEXT}.l.3280.f^2.\left|\mathcal{H}(l,f)\right|^2 \tag{9}$$

where variables are given as $K_{FEXT} = 3{,}083.10^{-20}$, l is the line length in km, f is the frequency in Hz and $\mathcal{H}(l,f)$ expresses the transfer function of a metallic homogeneous symmetric line.

2.3 Impulse noise signal

Due to the important effect of this negative influence, we took into account also this type of noise. The most common and the most damaging type of impulse noise seems to occur when a disturbed pair shares a common cable sheath with switched disturbing pairs – that is usual in the local access network. Sharp voltage changes can occur on analog pairs because of the opening and closing of relays. These voltage changes when are coupled into neighboring pairs through the NEXT and FEXT coupling path, create spurious, impulsive-like voltages whose amplitudes can be quite significant (Werner, 1991).

In unshielded twisted pairs, various equipments and environmental disturbances such as signaling circuits, transmission and switching gear, electrostatic discharges, lightning surges and so forth can generate an impulse noise. The impulse noise has some reasonably well-defined characteristics. Features of the typical impulse noise can be summarized as follows:

- occurs about 1-5 times per minute (on an average 4 times per minute),
- has peak values in the range 2 - 33 mV,
- has most of its energy concentrated below 40 kHz,
- has time duration in the range 30 - 150 μs.

Of course, mentioned features don't characterize all possible impulse noise signals. In the simulation model, therefore, characteristics of the impulse noise signal can be randomly varied.

2.4 Spectral characteristics of the VDSL signals

The VDSL modem uses a frequency bandwidth up to 20MHz. From this reason, the VDSL transmitter must solve situations that are not emergent in other xDSL modems. To these problems belong a spectral compatibility and cooperation with installed xDSL systems and a high level of different crosstalk signals.

In VDSL modems, various types of duplex methods and proposed modulation techniques are considered in (Cherubini et al., 2000), (Mestagh et al., 2000) and (Oksman & Werner, 2000). The ETSI recommendation binds producers to keep an established frequency plan (European Telecommunications Standards Institute [ETSI], 1999). The VDSL system can work in a frequency band bounded by frequencies f_{LOW} and f_{HIGH} (Fig. 2). In given frequency areas, the power of the VDSL signal must be adjusted to a level that can ensure the spectral compatibility with older xDSL systems. Alike, the signal level must be decreased to obviate undesirable emissions RFI, concretely caused by amateur radio stations.

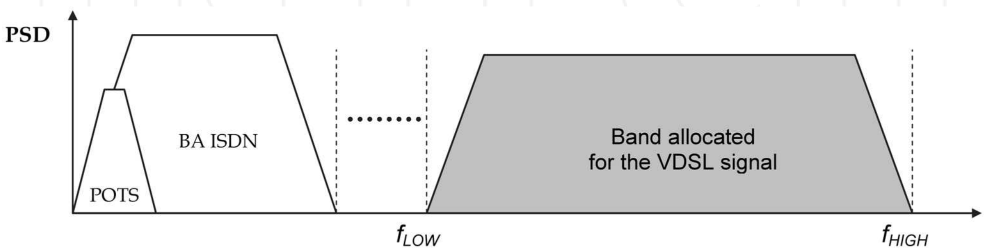

Fig. 2. The general frequency plan for the VDSL system

The lower frequency f_{LOW} is given by the spectral compatibility with narrowband services POTS and BA ISDN. The VDSL frequency plan depends on installation variations, on crosstalks from different sources and on the existence of narrowband services. Therefore, PSD masks of the VDSL signal are defined on the base of specific criteria. By (ETSI, 1999, 2001), we can discriminate between the VDSL deployment with or without the existence of narrowband services in the same cable and with or without the possibility for creating frequency apertures. The FTTEx variation seems to be the most probably variation of the VDSL deployment scenario where the line termination transceiver is placed in the central office exchange. Therefore, in our analysis, we used the FTTEx power spectral density mask. A graphical representation of the selected variation is shown on Fig. 3. If necessary, it is possible to assign any other standard spectral mask for the considered VDSL signal.

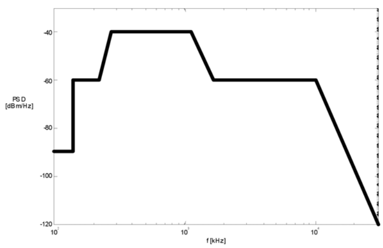

Fig. 3. The PSD mask of the VDSL signal for the FTTEx variation with narrowband services and the ADSL presence

2.5 Spectral characteristics of near-end and far-end crosstalk signals

Because crosstalk signals from the POTS service in disturbing pairs don't have significant influences on the VDSL signal in the disturbed pair, we supposed both disturbing and disturbed signals to have the same power spectral densities $PSD_1(f) = PSD_2(f)$. This situation is happened when in neighboring pairs are also VDSL signals – we can talk about the self-NEXT crosstalk and the self-FEXT crosstalk.

For local subscriber loops, we assigned the power spectral density of NEXT and FEXT crosstalks using relations (8) and (9) as follows

$$PSD_{NEXT}(f) = PSD(f).\left|\mathcal{H}_{NEXT}(l,f)\right|^2, \ \left|\mathcal{H}_{NEXT}(l,f)\right|^2 \approx K_{NEXT} \cdot f^{3/2} \quad (10)$$

$$PSD_{FEXT}(f) = PSD(f).\left|\mathcal{H}_{FEXT}(l,f)\right|^2, \left|\mathcal{H}_{FEXT}(l,f)\right|^2 \approx K_{FEXT}.l.3280.f^2.\left|\mathcal{H}\ (l,f)\right|^2 \quad (11)$$

where variables K_{NEXT} and K_{FEXT} are functions of disturbed pairs.

Equations (10) – (11) allow very well approximation of practically observed kind of multiple interferer crosstalks. Before starting of the simulation, we determined values of variables K_{NEXT} and K_{FEXT} in the simulation model as a function of the number of disturbing pairs N_d for typical 50-pairs cable as

$$K_{NEXT} = K_{NEXT-49} \cdot \frac{N_d^{\ 0.6}}{10} \quad (12)$$

$$K_{FEXT} = K_{FEXT-49} \frac{N_d^{0.6}}{10} \qquad (13)$$

The value of the $K_{NEXT-49}$ variable is given as 8,8.10[-14], the value of the $K_{FEXT-49}$ variable is empirically estimated as 8.10[-20]/3280 (Aslanis & Cioffi, 1992).

3. The simulation model for the VDSL technology

For considering of the signal transmission on metallic homogeneous lines by means of the VDSL technology, it is necessary comprehensively to know characteristics of negative environmental influences and features of applied modulation techniques. It is difficult to realize of the exact analytical description of complex systems such as the VDSL system in the real environment of local access networks. In addition, due to dynamical natures of some processes, it is not suitable. For analyzing of various signal processing techniques used by the VDSL technologies, a suitable and flexible enough tool are computer simulations and modeling schemes of real environmental conditions at the signal transmission.

For modeling of the VDSL transmission path, we used the software program *Matlab* together with additional libraries like *Signal Processing Toolbox* and *Communication Toolbox*. A proposed and realized modeling scheme represents a transmission of high-speed data signals in downstream and upstream directions by means of the VDSL technology utilizing of metallic homogeneous lines. The realized model (Fig. 4) represents the signal transmission in the VDSL environment utilizing metallic homogenous lines for high-speed data signals in the downstream and upstream direction. This VDSL environment model is the enhanced version of the ADSL environment model introduced (Róka & Cisár, 2002). New features of this simulation model are VDSL transmission characteristics and applications of precoding techniques and trellis coded modulations.

Basic functional blocks realized in our simulation model are shown on Fig. 4. The VDSL simulation model (Fig. 4) can be divided into the three main parts:

1. A transmitting part - it is responsible for the encoding (using the FEC technique) and for the modulation of signals into a form suitable for the transmission channel.
2. A transmission channel (the metallic homogenous line) - this part of the model realized negative influences on the transmitted signal. Above all, it goes about a propagation loss, a signal distortion, crosstalk noises, white and impulse noises, the radio interference. Because these negative influences expressively interfere into the communication and represent its main limiting factors, they present a critical part of the model and, therefore, it is necessary exactly to recognize and express their characteristics by correct parameters.
3. A receiving part - it is conceptually inverted in a comparison with the transmitter. Its main functions are the signal amplification, the removing of the ISI, the demodulation and the correction of errored information bits.

The analysis can be based on computer simulations that cover the most important features and characteristics of the real transmission environment for the VDSL technology and result in searching for the best combination of coding and precoding techniques.

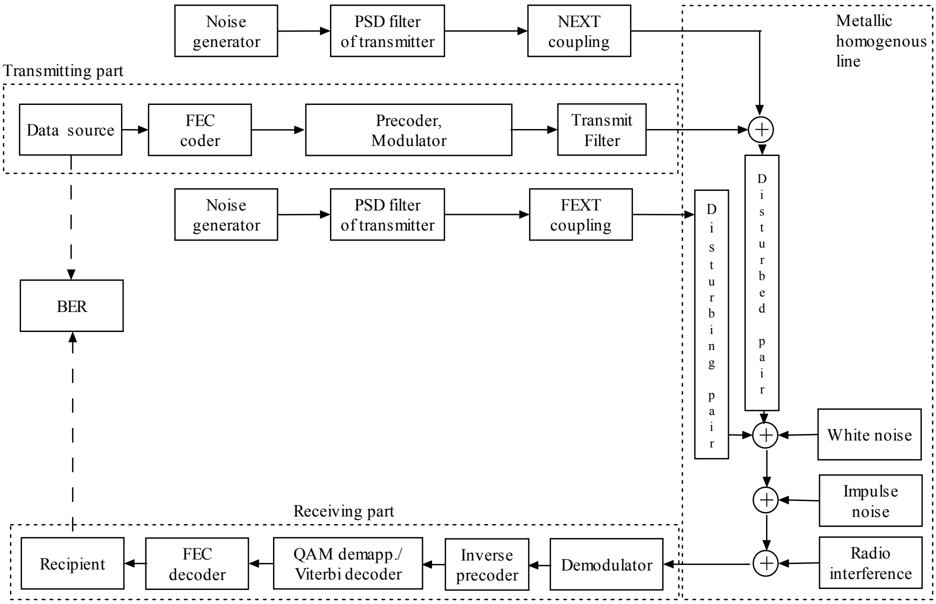

Fig. 4. The block scheme of the VDSL simulation model

3.1 The transmitting part of the model

The transmitted message carried to the receiving part is generated as a random binary chain with the given length. This message is also saved (for the BER calculation), encoded by a particular type of the FEC codes (RS, BCH) and modulated. It can be chosen from two kinds of modulations - the first one is the classical QAM modulation and the second one is a combination of the QAM and the convolutional coding, i.e. the TCM. The QAM modulation is chosen because of its compatibility with considered precoding techniques, a low distortion resistance and an easy implementation in the Matlab program environment.

3.2 The transmission line

Utilizing of local subscriber loops for the broadband access of subscribers by means of the VDSL technology assumes a replacing of the significant part of metallic lines by optical fibers. This will bring a subscriber distribution point (SDP) unit closer to subscribers, when metallic lines will distribute signals to subscriber premises. Although metallic lines will comprise only a small part of the transmission path, their influences on transmitted signals will not negligible.

Negative influences of the VDSL environment at the signal transmission depend on parameters of metallic homogeneous lines (a core material, a cable insulation, a core diameter, a number of neighboring lines in the cable binder, a cable length). If we want to achieve exact results from simulations, all these factors must be accepted. Of course, this acceptance leads to a complicated and complex simulation model. For modeling of all these influences, a theoretical description together with simulation methods is introduced (Róka & Cisár, 2002).

3.3 The receiving part of the model

At the receiver side, the distorted and attenuated signal is first amplified, next demodulated and then shifted into the inverse precoder that removes constellation changes introduced by the precoder at the transmitter side. If the TCM is used, the TCM decoder follows and the Viterbi algorithm is searching the most probably binary sequence. Otherwise, the QAM demapping block converts the constellation points sequence into the binary data sequence that is corrupted by transmission errors. They are consequently removed in the FEC decoder. Finally, the corrected sequence is compared with the original transmitted message and the bit error rate is calculated.

We should notice that individual precoding techniques suppose conceptually different manner of the signal regeneration, therefore this process is not here exactly described. For both methods, it is essential to know a transmission function of metallic lines. This information can be extracted from the signal transmission of predefined symbol sequences at the initialization process.

Before starting of the simulation, we can calculate the transmission function of the line for given parameters (l, ξ). Values of this function are sampled in equal proportioned frequency intervals in the range from 0 Hz up to the half of the sampling frequency ($f_{samp}/2$). A number of samples is optional. For signal processing, it is desirable to choice the number of samples equal to $2.N$, where N is an integer number. Using sampled values, the impulse characteristic of the transmission line $h(t)$ is calculated using the inverse Fourier transformation with the same number of samples (from practical viewpoint, the number of 512 samples is adequate). This sampled impulse characteristic is used as coefficients for the digital filter. A simulation of the signal transmission through the line itself is executed by digital filtering of the sampled modulated signal using the proposed filter. On Fig. 5, there are shown frequency characteristics of the transmission line ($\phi = 0{,}4$ mm, Cu) for various line lengths.

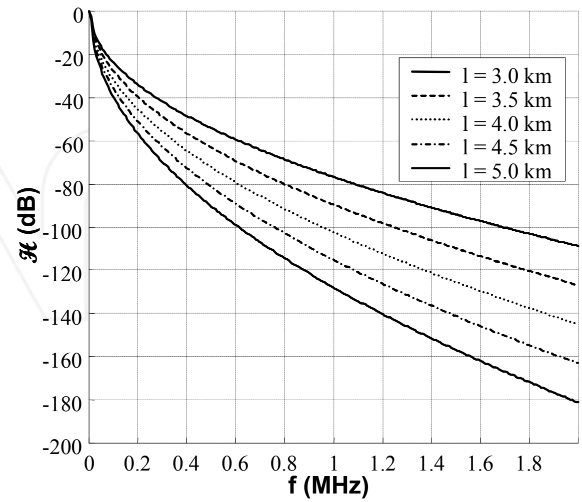

Fig. 5. Frequency characteristics of the transmission line for various line lengths

The influence of the transmission channel that we can derive from its transmission function is expressed above all at the attenuation of the transmitted signal. The signal attenuation is more accentuated for areas of higher frequency components of power spectral density characteristics. This influence is more expensive for longer line lengths. However, we can find out that the influence is decreased with increasing of the core diameter of wires. This results from a change of values for the primary constant of the line, concretely R and L.

We can create the NEXT crosstalk noise signal by forming of the white noise spectrum (with constant PSD = 0 dB/Hz) that is generated by a random number generator. First, we must calculate a frequency characteristic of the $\mathcal{H}_{NEXT}(l, f)$ crosstalk transmission function using (8). Its parameters are the number of disturbing pairs and the appropriate value of the variable K_{NEXT}. On Fig. 6, the NEXT crosstalk transmission function for various numbers of disturbers is presented. For modeling of the NEXT negative influence, the NEXT crosstalk noise signal acquired by filtering is added to the transmitted signal entering the transmission line.

The FEXT crosstalk signal is created in a similar manner as the NEXT crosstalk signal (its spectrum is presented on Fig. 6). Because this type of a crosstalk must be propagated through a disturbing line, we included into calculating the $\mathcal{H}_{FEXT}(l, f)$ crosstalk transmission function also the transmission function of the line $\mathcal{H}(l, f)$ using (9) with given parameters. The FEXT crosstalk signal is added to the transmitted information signal attenuated at a transmission through the metallic homogeneous line.

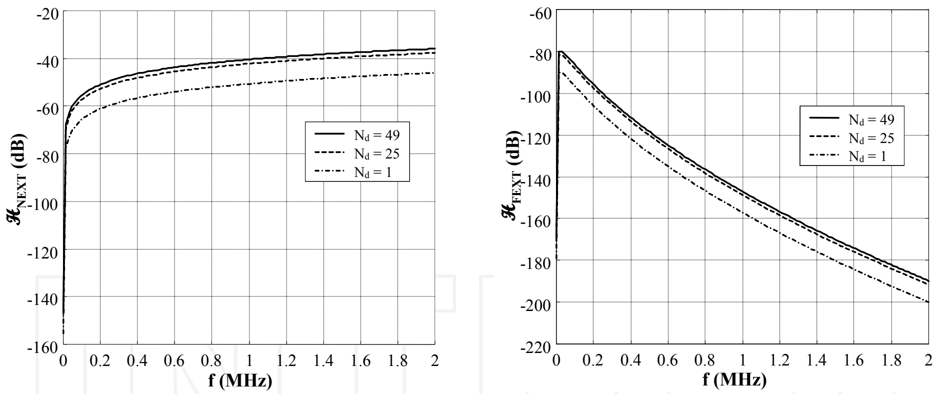

Fig. 6. The frequency characteristic of NEXT and FEXT crosstalk transmission functions for various numbers of disturbers

The influence of the FEXT crosstalk transmission function is characterized by the power spectral density of the FEXT crosstalk signal and by the FEXT crosstalk path. This FEXT crosstalk path is depend on the line length, on the frequency of signal and on the transmission function of the transmission line because of propagating of crosstalk signals through the disturbing pair. For longer line lengths, the influence of the FEXT crosstalk can be neglected. On other side, this influence is accentuated at higher frequency components of the transmitted signal. Therefore, it is necessary to take into account of the FEXT crosstalk for the new VDSL technology transmitting signals of asymmetric services and application at very high bit rates of information signals and on very short distances because of occupying higher frequency bandwidths of metallic homogeneous lines.

3.4 The analysis of environmental influences on the VDSL signals

At the analysis of the signal transmission through metallic homogeneous lines in the VDSL environment, we need to know three basic parameters - properties of the signal transmitted into the line (mainly its PSD), a transmission function of the transmission channel and features of the noise and crosstalk environmental influences.

In (Róka, 2002, 2004), particular relationships and frequency characteristics of basic noises and crosstalks occurred at the signal transmission through metallic homogeneous lines in the environment of xDSL technologies are introduced. The analysis of negative influences of noises and crosstalks on qualitative parameters of homogeneous lines can be extended to the VDSL environment. In our analysis, the NEXT crosstalk is not considered because this one can disable a communication in the VDSL frequency bandwidth. With respect to the possible VDSL deployments in conditions of the Slovak access network, we use a spectral mask defined for the FTTEx variation and for the coexistence with narrowband services in the same pair. In this spectral mask variation, the ADSL presence is supposed.

For the SCM modulation, four individual subbands are given alternatively for upstream and downstream directions of the transmission. Band transition frequencies are introduced in Tab. 1.

Band transition frequencies	f_1 [kHz]	f_2 [kHz]	f_3 [kHz]	f_4 [kHz]	f_5 [kHz]
VDSL subbands	138	3000	5100	7050	12000
Optional subbands	138	3750	5200	8500	12000
- The utilization of frequencies below f_1 and above f_5 but within the overall PSD masks is possible but is not covered (ETSI, 2001).					

Table 1. Band transition frequencies for the SCM FDD subbands according to the ETSI

Using a transmission function of the raised cosine filter and on the base of known values of carrier frequencies and symbol rates for particular subbands (Tab. 1), we can express an ideal PSD characteristic of the SCM signal. A signal transmitted into the metallic homogeneous lines must comply with the defined FTTEx spectral mask, so that a spectrum of the ideal SCM signal from the modulator must be digitally adjusted using FIR filters before transmitting. From this adjusted PSD, moreover, frequency components equivalent to subbands allocated for amateur radio stations should be eliminated (ETSI, 1999). Using appropriate FIR filters, the SCM signal can be also adjusted with respect to other FTTx spectral masks.

For the MCM modulation, a way to form the PSD of the signal transmitted from the transmitter is defined in the ETSI standard (ETSI, 2001). After simplifying, it is multiplying of every complex coefficient $Z_i = X_i + j.Y_i$ by a constant g_i and resulting complex coefficients $Z_i' = g_i \,.\, Z_i$ enter into the IFFT block. By this way, the transmitter can easy adapt any PSD characteristic of the transmitted VDSL signal for satisfying demands that are established by a chosen spectral mask. Alike, it is easy to keep frequency apertures in given subbands at occurrences of disturbing frequencies of the RFI type. Therefore, the MCM allows a high flexibility of the PSD transmitted signal and tries as effective as possible utilizations of the available bandwidth. We can therefore suppose that the transmitted VDSL signal will achieve maximum allowable levels in particular subchannels according to the FTTEx spectral mask (Fig. 3).

On Fig. 7 and 8, results of PSD characteristics of VDSL signals for the line length 0,5 km, the core diameter 0,4 mm with 24 ADSL and 9 VDSL disturbers and with the FTTEx spectral mask are introduced. On Fig. 7, the power spectral density of the SCM signal, the AWGN noise and the FEXT crosstalk are considered at the end of the line. All these characteristics are attenuated from a reason of transmitting signals through metallic homogeneous lines and, therefore, their corrections are needed. We are also using a linear equalization process to eliminate influences of the intersymbol interference (ISI). We can imitate this process by a corrector in the frequency area with a transmission function inverted to a channel transmission function. This correction in the frequency area eliminates aftereffects of the nonlinear signal attenuation by amplifying of higher frequency components. However, the correction of the received signal amplifies also the influence of noises and interferences. On Fig. 8, the PSD of the SCM signal and the total noise adjusted by the corrector are specified.

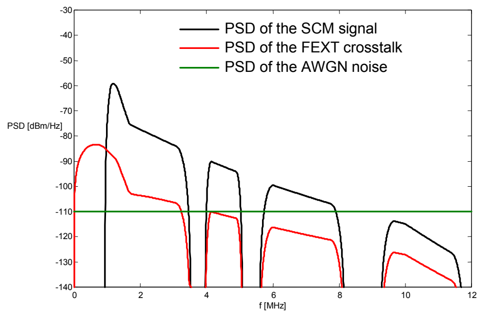

Fig. 7. The PSD characteristics of the SCM signal, the FEXT crosstalk and the AWGN noise attenuated at the end of the line

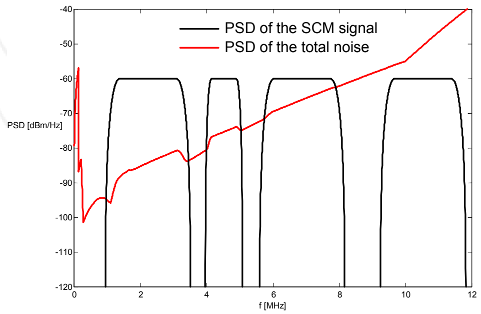

Fig. 8. The PSD characteristics of the SCM signal and the total noise adjusted by the corrector

On Fig. 9, results of PSD characteristics of the MCM signal, the AWGN noise and the FEXT crosstalk for the line length 0,5 km, the core diameter 0,4 mm with 24 ADSL and 9 VDSL disturbers and with the FTTEx spectral mask are introduced. A received signal is sampled and processed by the FFT block without a correction in the frequency area. Therefore, the SNR can be calculated in particular subchannels directly from the MCM signal power and the noise powers at the end of the line.

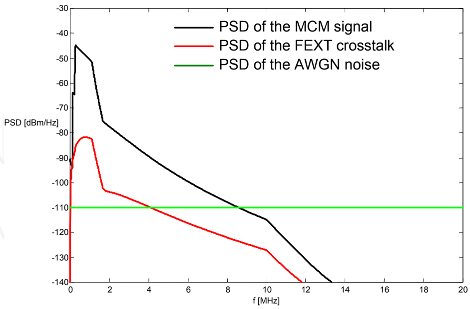

Fig. 9. The PSD characteristics of the MCM signal, the FEXT crosstalk and the AWGN noise attenuated at the end of the line

A sense of analyzing for environmental influences on the power spectral densities of VDSL signals is to identify all substantial noise resources and at the same time to determine a way for calculating of the signal-to-noise ratio for various proposed modulation techniques. For our following analysis of the VDSL system performance, the parameter *SNR* is very important. The signal-to-noise ratio for the subband given by the lowest f_{LOW} and the highest f_{HIGH} frequencies can be expressed as

$$SNR(f) = \frac{\int_{f_{LOW}}^{f_{HIGH}} PSD_S(f)\,df}{\int_{f_{LOW}}^{f_{HIGH}} PSD_N(f)\,df} \quad (14)$$

where $PSD_S(f)$ is the VDSL signal power spectral density and $PSD_N(f)$ is the noise power spectral density. The $SNR(f)$ ratio must be calculated from the adjusted SCM signal power and the noise powers.

4. The environment of power distribution cables

4.1 The multipath signal propagation

The PLC transmission channel has a tree-like topology with branches formed by additional wires tapered from the main path and having various lengths and terminated loads with highly frequency-varying impedances in a range from a few ohms to some kiloohms (Zimmermann & Dostert, 2002b), (Held, 2006). That's why the PLC signal propagation does not only take place along a direct line-of-sight path between a transmitter and a receiver but also additional paths are used for a signal spreading. This multipath scenario can be easily explained by the example of a cable with one tap (Fig. 10).

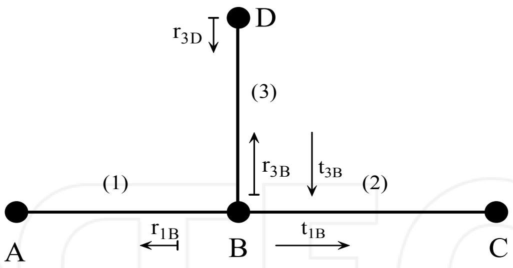

Fig. 10. The multipath signal propagation in the cable with one tap

The line consists of three segments (A-B), (B-C) and (B-D) with lengths l_1, l_2, l_3 and characteristic impedances Z_{L1}, Z_{L2} and Z_{L3}. To simplify considerations, points A and C are assumed to be matched, which means $Z_A = Z_{L1}$ and $Z_C = Z_{L2}$. Then, points B and D are reflection points with reflection factors are denoted as r_{1B}, r_{3D}, r_{3B} and transmission factors are denoted as t_{1B}, t_{3B}. Because of multiple reflections, a number of propagation paths is infinitive (i.e., A → B → C, A → B → D → B → C, and so on). An affect of all reflections and transmissions can be expressed for each propagation path i in a form of the weighting factor g_i that is mathematically equal to the product of reflection and transmission factors along the path. The value g_i is always less or equal to one because all reflection and transmission factors can be only less or equal to one. The simulation model can be simplified if we approximate infinite number of paths by only N dominant paths and make N as small as possible. When more transmissions and reflections occur along the path, then the weighting factor will be smaller. When the longer path will be considered, then the signal contribution from this part to the overall signal spreading will be small due to the higher signal attenuation (Ferreira et al., 2010).

4.2 The signal attenuation

Characteristics of the PLC transmission environment focused on the multipath signal propagation, the signal attenuation, the noise scenario and the electromagnetic compatibility are introduced in (Róka & Dlháň, 2005). First, we can present basic characteristics of the PLC channel.

A total signal attenuation on the PLC channel consists of two parts: coupling losses (depending on a transmitter design) and line losses (very high and can range from 40 to 100 dB/km). To find a mathematical formulation for the signal attenuation, we have to start with the complex propagation constant

$$\gamma(\omega) = \sqrt{(R + j.\omega.L)\cdot(G + j.\omega.C)} = \alpha(\omega) + j.\beta(\omega) \qquad (15)$$

depending on the primary cable parameters R, L, G, C. Then, the frequency response of a transmission line $\mathcal{H}(f)$ (the transfer function) with the length l can be expressed as follows ($\mathcal{U}(x)$ is the voltage at the distance x):

$$\mathcal{H}(f) = \frac{\mathcal{U}(x=l)}{\mathcal{U}(x=0)} = e^{-\gamma(f)\cdot l} = e^{-\alpha(f)\cdot l} e^{-j\cdot\beta(f)\cdot l} \tag{16}$$

Considering frequencies in the megahertz range, the resistance R per length unit is dominated by the skin effect and thus is proportional to $\sqrt{f}$. The conductance G per length unit is mainly influenced by a dissipation factor of the dielectric material (usually PVC) and therefore proportional to f. With typical geometry and material properties, we can suppose $G << \omega.C$ and $R << \omega.L$ in the frequency range of interest. Then, cables can be regarded as low lossy ones with real valued characteristic impedances and a simplified expression for the complex propagation constant γ can be introduced

$$\gamma(f) = k_1 \cdot \sqrt{f} + k_2 \cdot f + j \cdot k_3 \cdot f = \alpha(f) + j.\beta(f) \tag{17}$$

where constants k_1, k_2 and k_3 are parameters summarizing material and geometry properties. Based on these derivations and an extensive investigation of measured frequency responses, an approximating formula for the attenuation factor α *(f)* is found in a form

$$\alpha(f) = a_0 + a_1 \cdot f^k \tag{18}$$

that is able to characterize the attenuation of typical power distribution lines with only three parameters, being easily derived from the measured transfer function (Zimmermann & Dostert, 2002b). Now the propagation loss L_{dB} is given at the length l and the frequency f as

$$\begin{aligned} L_{dB}(l,f) = -20.\log_{10}\left|\mathcal{H}(l,f)\right| = \frac{20}{\ln 10}.l.\alpha(f) = \frac{20}{\ln 10}.l.(a_0 + a_1.f^k) \quad [Np] \\ \approx 8,686.l.(a_0 + a_1.f^k) \quad [dB] \end{aligned} \tag{19}$$

We can see a linear dependence of the propagation loss L_{dB} on the line length l. Parameters a_0, a_1 and k are characterized by measurements of the transfer function $\mathcal{H}$ *(f)* that is much easier then the measurement of primary line parameters *R, L, C, G*. If we now merge a signal spreading on all paths together (we can use a superposition), we can receive an expression for the frequency response $\mathcal{H}$ *(f)* in a form

$$\mathcal{H}(f) = \sum_{i=1}^{N} g_i \cdot a(l_i, f) \cdot e^{-j.2.\pi.f.\tau_i} \tag{20}$$

where $a\ (l_i, f)$ is the signal attenuation proportioned with the length and the frequency and N is the number of paths in the transmission channel. The delay τ_i of the transmission line can be calculated from the dielectric constant ε_r of insulating materials, the light speed c and the line length l_i as follows

$$\tau_i = \frac{l_i \cdot \sqrt{\varepsilon_r}}{c} \tag{21}$$

4.3 The noise scenario

Unfortunately, in a case of the PLC environment, we can't stay only with the additive white Gaussian noise. The noise scenario is much more complicated, since five general classes of noise can be distinguished in power distribution line channels (Zimmermann & Dostert, 2002a), (Götz et al., 2004). These five classes are (Fig. 11):

1. *Colored background noise* – caused by a summation of numerous noise sources with low powers. Its PSD varies with the frequency in a range up to 30 MHz (significantly increases toward to lower frequencies) and also with the time in terms of minutes or even hours.
2. *Narrowband noise* – caused by ingress of broadcasting stations. It is generally varying with daytimes and consists mostly of sinusoidal signals with modulated amplitudes.
3. *Periodic impulsive noise asynchronous with the main frequency* – caused by rectifiers within DC power supplies. Its spectrum is a discrete line spectrum with a repetition rate in a range between 50 and 200 kHz.
4. *Periodic impulsive noise synchronous with the main frequency* – caused by power supplies operating synchronously with the main cycle. Its PSD is decreasing with the frequency and a repetition rate is 50 Hz or 100 Hz.
5. *Asynchronous impulsive noise* – caused by impulses generated by the switching transients' events in the network. It is considered as the worst noise in the PLC environment, because of its magnitude that can easily reach several dB over other noise types. Fortunately, the average disturbance ratio is well below 1 percent, meaning that 99 percent of the time is absolutely free of the asynchronous impulsive noise.

The noise types 1, 2 and 3 can be summarized as background noises because they are remaining stationary over periods of seconds and minutes, sometimes even of hours. On the contrary, the noise types 4 and 5 are time-variant in terms of microseconds or milliseconds and their impact on useful signals is much more stronger and may cause single-bit or burst errors in a data transmission. Time and domain analysis of impulse noises can be found in (Zimmermann & Dostert, 2002a). We will just mention a few expressions regarding a mathematical description of the impulse noise model and the impulse energy and power.

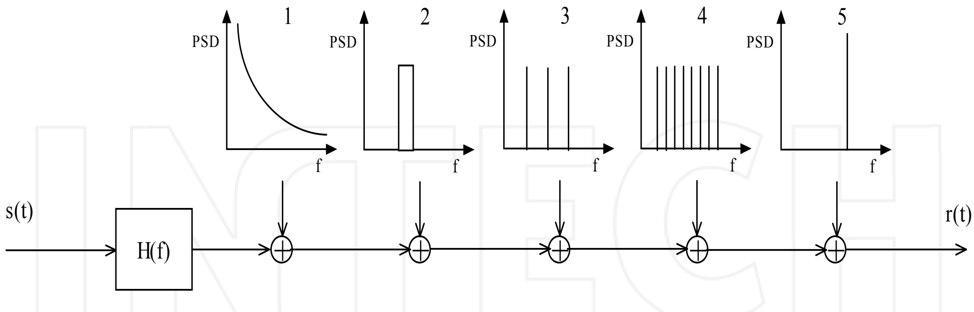

Fig. 11. The noise scenario in the PLC environment

A time behavior of the impulsive noise can be described by three basic figures, i.e. the impulse width t_w, the arrival time t_{arr} and the interarrival time t_{iat} or the impulse distance t_d. The interarrival time (the impulse distance) means a distance between two impulse events that can be described by

$$t_{iat} = t_w + t_d = t_{arr,i+1} - t_{arr,i} \tag{22}$$

Then, a train of impulses $n_{imp}(t)$ can be described as

$$n_{imp}(t) = \sum_{i=1}^{N} A_i \cdot imp\left(\frac{t - t_{arr,i}}{t_{w,i}}\right) \tag{23}$$

where A_i means the impulse amplitude and $imp(t)$ is the generalized impulse function. The parameters A_i, t_w and t_{arr} are random variables, whose statistical properties may be investigated by measurements. More information can be found in (Róka & Urminský, 2008).

The best way how to characterize extent of the impact of impulses on a data transmission are values of the impulse energy and the impulse power. The impulse energy E_{imp} can be calculated from the time-domain representation $n_{imp}(t)$ as

$$E_{imp} = \int_{t_{arr}}^{t_{arr}+t_w} n_{imp}(t)^2 \, dt \tag{24}$$

As we can see from (24), the impulse energy is influenced by the impulse shape and width. Finally, the impulse power can be determined by

$$\psi_{imp} = \frac{1}{t_w} \int_{t_{arr}}^{t_{arr}+t_w} n_{imp}(t)^2 \, dt \tag{25}$$

and can be used for a comparison of impulse and background noises.

5. The simulation model for the PLC technology

The realized model (Fig. 12) represents a high-speed signal transmission in the PLC system utilizing outdoor power distribution lines in downstream and upstream directions (Róka & Dlháň, 2005). The signal transmission over outdoor power distribution lines represents the transmission between a transmitter in the transformer substation and a receiver in the customer premises.

Our realized simulation model can be divided into the three main parts:

1. A transmitting part - it is responsible for the encoding (because of using the FEC technique) and for the modulation of signals into a form suitable for the transmission channel.
2. A transmission channel (the outdoor power lines) - this part realizes negative influences of the PLC environment on the transmitted signal. Above all, it goes about the propagation loss, the signal distortion, the impulsive, colored and narrow-band noises.
3. A receiving part - it is conceptually inverted in a comparison with the transmitter. Its main functions are the signal amplification, the demodulation and the correction of error information bits.

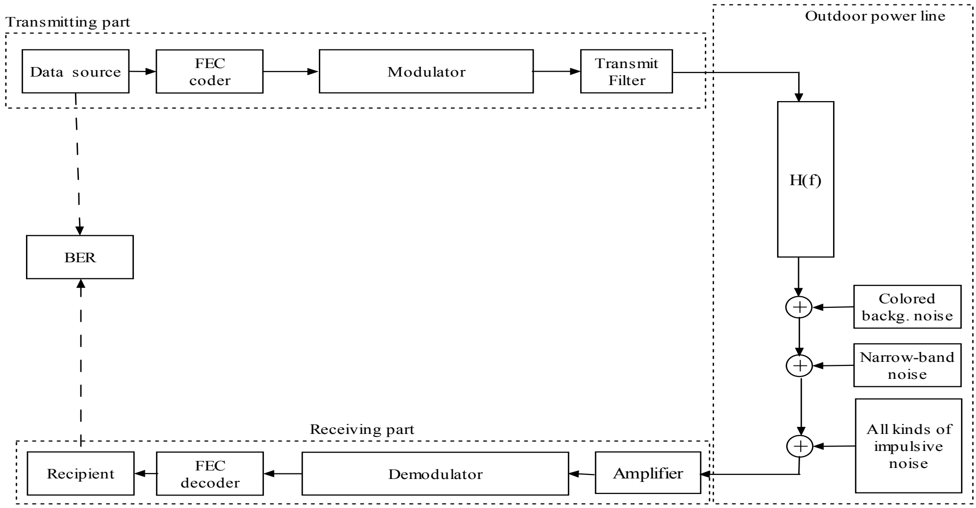

Fig. 12. The block scheme of the PLC simulation model

5.1 The transmitting part of the model

The transmitted message carried to the receiving part is generated as a random binary chain with the given length. This message is also saved (for the BER calculation), encoded by a particular type of the FEC codes and modulated. From the coding and modulation techniques, we are intending to implement several different ones to be able to compare them and find the most appropriate one.

5.2 The outdoor power distribution line

Negative influences of the PLC environment at the signal transmission depend on parameters of power distribution lines (a core material, a cable insulation, a cable length, a core diameter, a number, position and properties of additional wires tapered from the main path) as well as on number and properties of points of nonhomogenity (instrument panels, PLC signal coupling units, regenerator units, points of wires interconnections). If we want to achieve exact results from simulations, all these factors must be accepted. Of course, this acceptance leads to a complicated and complex PLC simulation model. Because of this fact we have to choose a trade-off between the model complexity and the accuracy of reality representations. For modeling of the PLC transmission channel, we chose a generalized multipath model because of its accuracy, easily implementation and understandability (Zimmermann & Dostert, 2002b). Mathematically, it can be described in a form of the expression

$$\mathcal{H}(f)=\sum_{i=1}^{N} g_i \cdot a(l_i, f)\cdot e^{-j.2.\pi.f.\tau_i}=\sum_{i=1}^{N}\left|g_i(f)\right|\cdot e^{\phi_{g_i}(f)}\cdot e^{-(a_0+a_1.f^k)\cdot l_i}\cdot e^{-j.2.\pi.f.\tau_i} \tag{26}$$

In general, the weighting factor g_i is complex and frequency-dependent because reflection points may have complex and frequency-dependent values. According to extended measurements campaigns, it is possible to consider g_i as a complex but not frequency-dependent value or as a real value even in many practical models it can be considered.

For the presented model, parameters were assumed from the paper (Zimmermann & Dostert, 2002b). In spite of its simplification, it is still accurate enough for the PLC system performance analyses. It goes about the model of the 110 m link supposing N = 15 main paths. The values of other parameters like k, a_0, a_1, g_i, l_i (k, a_0, a_1 are attenuation factors, g_i is weighting factor and finally l_i means length of i-th branch) can be found in Tab. 2.

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
g_i	0,029	0,043	0,103	-0,058	-0,045	-0,040	0,038	-0,038	0,071	-0,035	0,065	-0,055	0,042	-0,059	0,049
l_i [m]	90	102	113	143	148	200	260	322	411	490	567	740	960	1130	1250
k	1														
a_0	0														
a_1 [m/s]	$7{,}8.10^{-10}$														

Table 2. Parameters of the 15-path PLC simulation model

In the PLC transmission environment, not only a signal distortion expressed by the channel transfer function $\mathcal{H}(f)$ is presented. Also different types of noise have very negative influence on transmitted signals in a form of the time-invariant behavior of the SNR on powerline channels. The first type of noise – the colored background noise is modeled by filtering the AWGN noise through a filter with the exponentially decreasing transfer function for increasing frequencies with the average 35 dB/decade in the low frequency range up to 10 kHz and a low rate in the high frequency range (Hrasnica et al., 2004). The narrowband noise is generated in a similar way only with a difference in band-pass filters with a random selection of the lower passband edge frequency. The power of these narrow spikes is varying around the –80 dBm/Hz. The impulsive noise can be described by expression (23). From (Zimmermann & Dostert, 2002a), the parameters of periodic impulsive noises (type 3 and 4) are more and less deterministic. Concretely, the width of noise impulse is about 200 μs, the impulse amplitude is concentrated around two values; about 0.4 V and then between 0.7 and 1 V. The interarrival time values are 10 ms, 6 ms and 12 ms.

The biggest problem for modeling represents the asynchronous impulsive noise because of its random occurrence and random durations from some microseconds up to a few milliseconds. It can’t be ignored since its influence with the PSD more than 50 dB is particularly devastating of the transmitted signal. As it goes about a random process, whose a future behavior only depends on the present state or on limited periods in the past, may be described by so-called the portioned Markov chain. In this model, all states are partitioned into two groups, where the first represents a case where no impulse event occurs and the second represents an occurrence of the impulse event. Transitions between states from the first group top the second and vice versa are described by two independent probability matrices U for impulse-free states and G for impulse states. The concrete values of these matrices can be found in paper (Zimmermann & Dostert, 2002a). Each impulsive noise state corresponds to an exponential distribution of the impulse width, while each impulse-free state corresponds to an exponential distribution of the impulse distance. Thus, this kind of modeling represents a superposition of several exponential distributions that approximate real scenarios very well.

5.3 The receiving part of the model

At the receiver side, the distorted and attenuated signal is first amplified and then demodulated. Part of the demodulation is also demapping block as a part of modulator, which is responsible for converting the constellation points sequence into the binary data sequence corrupted by transmission errors. They are consequently removed in the FEC decoder. Finally, the corrected sequence is compared with the original transmitted message and the bit error rate is calculated.

5.4 Characteristics of the parametric model for reference channels

The parametric model for the PLC channel is possible to adapt for any topology of the power distribution network (Róka & Urminský, 2008). Parameters of this model with various coefficients were presented in ETSI Technical Specifications (ETSI, 2000, 2001) and a following set of reference channels for a practical utilization was established:

1. *Reference channel 1* (RC1) – a channel between transformer stations with features of the HV channel. A distance between separate transformer stations is around 1000 m.
2. *Reference channel 2* (RC2) – a channel from the transformer station up to the main circuit breaker, a distance is approximately 150 m.
3. *Reference channel 3* (RC3) – a channel from the main circuit breaker up to the counting box of consumed energy in the house, a distance is maximum 250 m.
4. *Reference channel 4* (RC4) – a home scenario.

For the presented parametric model, parameters for various PLC reference channels were assumed from the paper (Zimmermann & Dostert, 2002b). In spite of their simplification, it is still accurate enough for the PLC system performance analyses. The values of other parameters like k, a_0, a_1, g_i, l_i for the multi-path signal propagation in reference channels can be found in (Róka & Urminský, 2008). Computer simulations at appropriate frequency characteristics of particular reference channels used values from a specific table. These frequency responses are graphically shown in Fig. 13.

As it can be noticed from simulation results, the signal attenuation in reference channels is straightforward proportioned with the length and the frequency. For some specific frequencies only is shown the selective attenuation caused by the multi-path effect with approximately 30 to 40 dB.

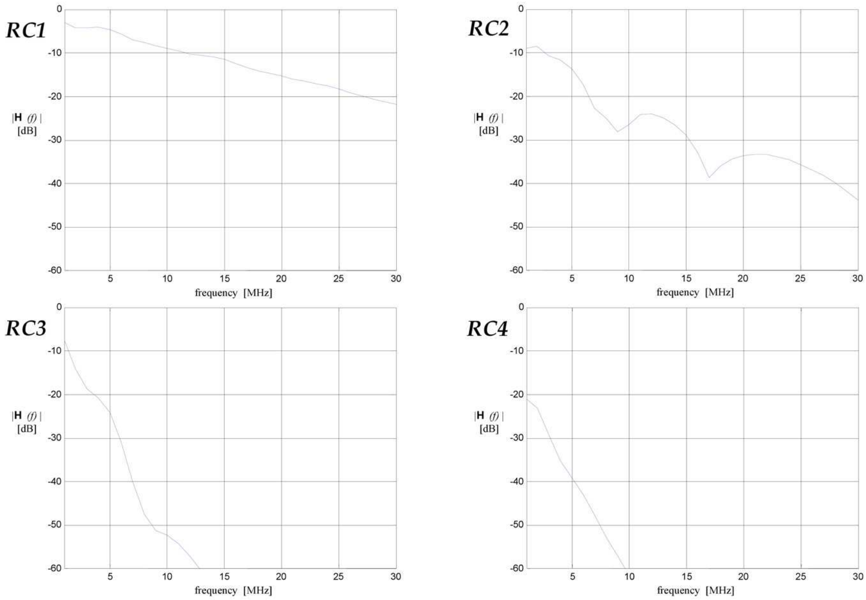

Fig. 13. Frequency responses of the RC1, RC2, RC3 and RC4 channels

6. The environment of optical fibers

6.1 Transmission parameters of the optical fiber

Basic transmission factors of the singlemode standard optical fiber are following (Čuchran & Róka, 2006):

- the attenuation,
- the dispersion
    - the chromatic dispersion CD,
    - the polarization mode dispersion PMD,
- nonlinear effects – the self phase modulation SPM,
    - the cross phase modulation XPM,
    - the cross polarization modulation XPolM,
    - the four wave mixing FWM,
    - the stimulated Raman scattering SRS,
    - the stimulated Brillouin scattering SBS.

Nonlinear effects in the optical fiber may potentially have a significant impact on the performance of WDM optical communication systems. In a WDM system, these effects place constraints on the spacing between adjacent wavelength channels and they limit the maximum power per channel, the maximum bit rate and the system reach (Mukherjee, 2006).

Knowing which fundamental linear and nonlinear interactions dominate is helpful to conceive techniques that improve a transmission of optical signals, including advanced modulation formats, a digital signal processing and a distributed optical nonlinearity management.

6.2 The attenuation

The optical fiber is an ideal medium that can be used to carry optical signals over long distances. There are several sources that contribute to the fiber attenuation, such as an absorption, a scattering and a radiation. The attenuation leads to a reduction of the signal power as the signal propagates over some distance. When determining the maximum distance that a signal propagate for a given transmitter power and receiver sensitivity, the attenuation must be considered. The attenuation coefficient α [dB/km] of the optical fiber can be obtained by measuring the input and the output optical power and then the optical power level along the fiber length L [km] can be expressed as

$$P(L)=10^{\frac{-\alpha . L}{10}} . P(0) \qquad [W] \tag{27}$$

where $P\ (0)$ is the optical power at the transmitter, $P\ (L)$ is the optical pulse power at the distance L. For the link length L, the $P\ (L)$ must be greater than or equal to the receiver sensitivity Pr. On Fig. 14, a characteristic curve of the $\alpha\,(\lambda)$ as a function of available wavelengths is presented (Black, 2002).

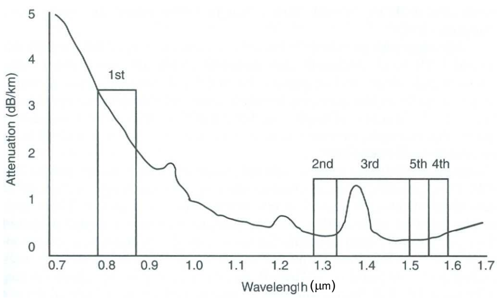

Fig. 14. The wavelength characteristic of the attenuation coefficient α

6.3 The dispersion

The dispersion is a widening of the pulse duration as it travels through the optical fiber. As a pulse widens, it can broaden enough to interfere with neighboring pulses (bits) on the fiber leading to the intersymbol interference ISI. The dispersion thus limits the maximum transmission rate on a fiber-optic channel. We distinguished two basic dispersive forms - the intermodal dispersion and the chromatic dispersion. Both cause an optical signal distortion in multimode optical fibers MMF, whereas a chromatic dispersion is the only cause of the optical signal distortion in singlemode fibers SMF.

The chromatic dispersion CD represents a fact that different wavelengths travel at different speeds, even within the same mode. In a dispersive medium, the index of refraction $n\ (\lambda)$ is a function of the wavelength. Thus, certain wavelengths of the transmitted signal will propagate faster than other wavelengths. The CD dispersion is the result of material dispersion, waveguide dispersion and profile dispersion. On Fig. 15, characteristic curves of the CD as a function of available wavelengths for various optical fiber types (USF, NZDF, DSF) are presented (Black, 2002).

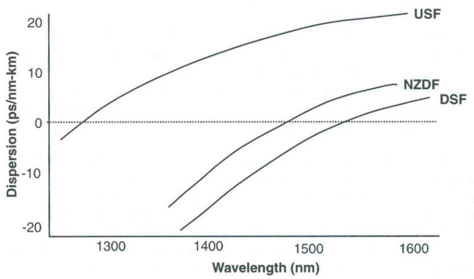

Fig. 15. Wavelength characteristics of the dispersion for USF, NZDF and DSF fibers

The polarization mode dispersion PMD is another complex optical effect that can occur in singlemode optical fibers (Black, 2002). The SMF support two perpendicular polarizations of the original transmitted signal. If a fiber is not perfect, these polarization modes may travel at different speeds and, consequently, arrive at the end of the fiber at different times. The difference in arrival times between the fast and slow mode axes is the PMD (Fig. 16). Like the CD, the PMD causes digitally-transmitted pulses to spread out as the polarization modes arrive at their destination at different times.

$$\Delta\tau = D_{PMD} . \sqrt{L} \tag{28}$$

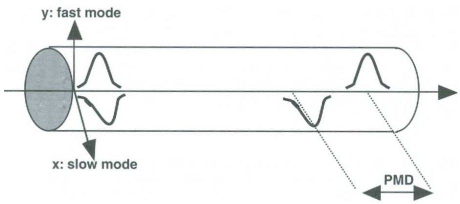

Fig. 16. The PMD generation in the environment of optical fibers

The main problem with the PMD in optical fiber systems is its stochastic nature, letting the principal state of polarization PSP and the differential group delay DGD vary on timescales between milliseconds and months (Kaminow et al., 2008).

6.4 The insertion loss

The fiber loss is not only source of the optical signal attenuation along transmission lines. Fiber splices and fiber connectors also cause the signal attenuation. The number of optical splices and connectors depends on the transmission length and must be taken into account unless the total attenuation due to fiber joints is distributed and added to the optical fiber attenuation.

7. The simulation model for the optical communications

For modeling of the optical transmission path, we used the software program *Matlab 2010 Simulink* together with additional libraries like *Communication Blockset* and *Communication Toolbox* (Schiff, 2006), (Binh, 2010). The realized model (Fig. 17) represents the signal transmission in the environment utilizing optical fibers for very high-speed data signals in both directions. Optical communication technologies will always be facing the limits of high-speed signal processing and modulation, which is an important factor to take into account when discussing advanced optical modulation formats. The main task of the simulation model is an analysis of various modulation techniques (Xiong, 2000), (Kaminow et al., 2008), (Shieh & Djordjevic, 2010).

Basic functional blocks realized in the optocommunication simulation model can be divided into the three main parts:

1. A transmitting part - it is responsible for the generating (using the Bernoulli generator) and for the modulation of generated signals according to required information inputs into a form suitable for the transmission channel. The modulation block contains a basic set OOK modulation and its variations with DBPSK and DQPSK modulations.
2. A transmission channel (the optical fiber) - this part of the model realized negative influences on the transmitted signal. Above all, it goes about an attenuation, a dispersion and a noise. Because these negative influences expressively interfere into the communication and represent its main limiting factors, they present a critical part of the model and, therefore, it is necessary exactly to recognize and express their characteristics by correct parameters.
3. A receiving part - it is conceptually inverted in a comparison with the transmitter. At the receiver side, a signal is demodulated by appropriate demodulator and the BER ratio is calculated. Also, blocks for graphical presenting of transmitted optical signals can be utilized (Fig. 18).

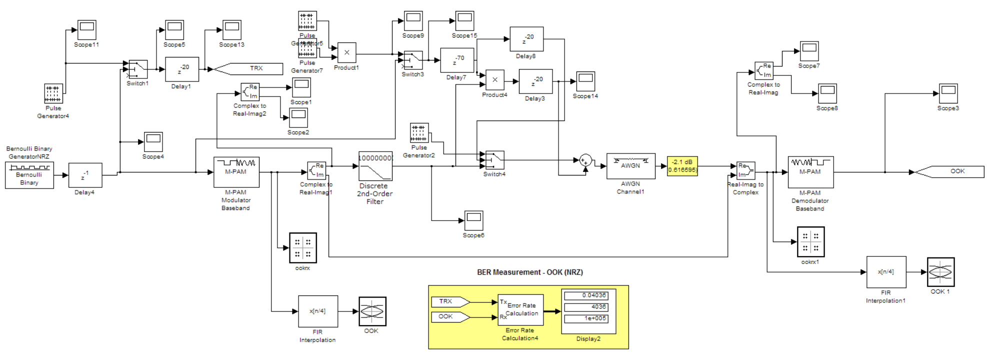

Fig. 17. The block scheme of the optocommunication simulation model

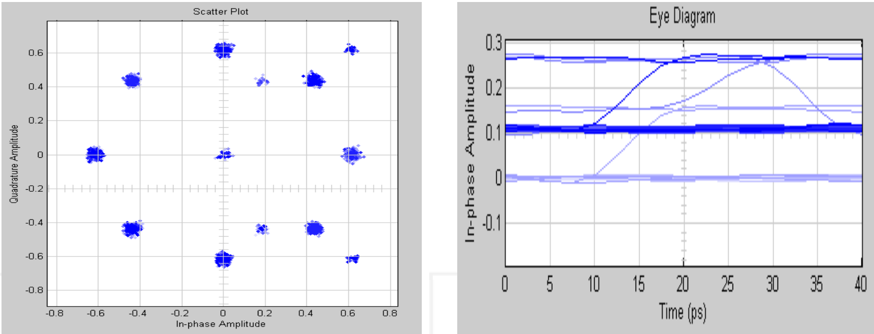

Fig. 18. Symbol constellation and eye diagrams of the DQPSK modulations

8. Conclusion

The first part of the paper analyzes basic features of the real transmission environment of metallic homogeneous lines and presents possibilities for modeling and simulating of the information signal transport in this environment by means of the VDSL technology. We focused on the determination and the analysis of concrete characteristic features for substantial negative influences of internal and external environments and on the representation of frequency dependencies of transmitted VDSL signals. The attenuation determined by the channel's transmission function is more damaged for areas of higher frequency components of power spectral density characteristics for transmitted signals. The influence of the NEXT crosstalk signal is accentuated at higher frequency components of the transmitted signal. The influence of the FEXT crosstalk signal is depending on the line length, on the frequency of signal and on the transmission function of the transmission line because of propagating of crosstalk signals through the disturbing pair. For long enough line lengths, the influence of the FEXT crosstalk can be neglected. Therefore, for the VDSL technology that transmits information signals of asymmetric and symmetric services at very high bit rates on very short distances, it is necessary to take into account both NEXT and FEXT crosstalks at signals occupying higher frequency bandwidths of metallic homogeneous lines. Due to damaging effects of the impulse noise, we must take into account also this type of negative environmental influence.

Basic features and characteristics of negative environmental influences at the signal transmission in the VDSL environment can be used for modeling spectral characteristics of signals on the transmission path. The VDSL simulation model allows determining main problems that can arise at the VDSL signal transmission. For realizing of individual model blocks, we concentrated on the choice of appropriate parameters so that these blocks could be adjusted and modified for future demands. The knowledge of the PSD characteristics of the VDSL signal can be very effectively utilized for characterizing the VDSL signal transmission on metallic homogeneous symmetric lines, especially for a determination of the SNR ratio. In addition, they can be used for analyzing singlecarrier and multicarrier modulation techniques in the overall VDSL system performance including theoretical and practical limits of transmission channels used by the VDSL technology.

The second part of the paper analyzes basic features of the real transmission environment of the outdoor power distribution lines and presents possibilities for modeling and simulation of the information signal transmission in this environment by means of the PLC technology. We focused on transmission characteristics of the PLC channel, namely the multipath signal propagation, the signal attenuation and the interference scenario revealing different classes of the impulsive noise. We created a model of the complex frequency response in a range from 500 kHz up to 30 MHz. Moreover, we realized experimental measurements for verification of the parametric model for reference channels. According the transfer functions, it has been observed the decreasing linear performance in the measured frequencies range where the number of imperfect matching points is minimum. It can be concluded that if the line length path grows it is more probable that the number of reflections produced by imperfect matching points grows too. Moreover, the transfer function slope increasing in lower frequencies is proportional to the line length.

Basic features of negative environmental influences at the signal transmission in the power distribution environment can be used for modeling spectral characteristics of PLC signals of the transmission path. The PLC simulation model is verified by measurements in the real PLC transmission environment that confirmed its satisfactory conformity with real transmission conditions. Using the PLC simulation model, it is possible to verify a correctness of the proposed model, to compare with other ones and to demonstrate its suitability for searching the most appropriate coding and modulation techniques that belong among critical requirements of the development of the next generation PLC communication systems with higher data rates. In spite of problems with a high-frequency signal transmission, power distribution lines remain a very interesting transmission medium. Therefore, it is necessary to evolve a technology that is able to overcome various noises and interferences incident in the PLC environment.

The third part of the paper analyzes transmission parameters for the transmission medium of optical fibers and presents possibilities for modeling and simulation of the information signal transmission in the environment of optical channels. We focused on linear transmission factors – the attenuation and the dispersion - and on nonlinear effects. Nonlinear effects in the optical fiber may potentially have a significant impact on the performance of WDM optical communication systems.

The simulation model for the optical communications represents the signal transmission in optical fibers for very high-speed data signals in both directions. Knowing which fundamental linear and nonlinear interactions dominate in the optical transmission medium is helpful to conceive techniques that improve a transmission of optical signals, including advanced modulation formats, a digital signal processing and a distributed optical nonlinearity management.

9. Acknowledgment

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10. Abbreviations

ADSL	Asymmetric DSL
AWGN	Additive White Gaussian Noise
BA ISDN	Basic Access ISDN
BER	Bit Error Rate
BCH	Bose-Chaudury-Hocquenghem
CD	Chromatic Dispersion
DBPSK	Differential Binary Phase Shift Keying
DGD	Differential Group Delay
DQPSK	Differential Quadrature Phase Shift Keying
DSF	Dispersion Shifted Fiber
ETSI	European Telecommunications Standards Institute
FEC	Forward Error Correction
FEXT	Far-End Crosstalk
FDD	Frequency Division Duplex
FTTEx	Fiber To The Exchange
FWM	Four Wave Mixing
ISI	Inter-Symbol Interference
MCM	Multi-Carrier Modulation
MMF	Multi-Mode Fiber
NEXT	Near-End Crosstalk
NZDF	Non-Zero Dispersion shifted Fiber
OOK	On-Off Keying
PLC	Power Line Communication
PMD	Polarization Mode Dispersion
POTS	Plain Old Telephone Service
PSD	Power Spectral Density
PSP	Principal State of Polarization
QAM	Quadrature Amplitude Modulation
RC	Reference Channel
RFI	Radio Frequency Interference
RS	Reed-Solomon
SBS	Stimulated Brillouin Scattering
SCM	Single-Carrier Modulation
SDP	Subscriber Distribution Point
SMF	Single-Mode Fiber
SNR	Signal-to-Noise Ratio
SPM	Self Phase Modulation
SRS	Stimulated Raman Scattering
TCM	Trellis-Coded Modulation
USF	Dispersion Unshifted Fiber
VDSL	Very high bit rate DSL
WDM	Wavelength Division Multiplexing
xDSL	“x” Digital Subscriber Line
XPM	Cross Phase Modulation
XPolM	Cross Polarization Modulation

11. References

Aslanis, J. T.; Cioffi, J. M. (1992). Achievable information rates on digital subscriber loops: Limiting information rates with crosstalk noise. *IEEE Transactions on Communications*, Vol.40, No.2, (February 1992), pp. 361-372, ISSN 0090-6778

Binh, L.N. (2010). *Optical Fiber Communications Systems*, CRC Press, ISBN 978-1-4398-0620-3, Boca Raton, United States of America

Black, U. (2002). *Optical Networks – 3rd Generation Transport Systems*, Prentice Hall PTR Inc., ISBN 0-13-060726-6, New Jersey, United States of America

Čuchran, J.; Róka, R. (2006). *Optocommunication Systems and Networks*, STU Publishing house, ISBN 80-227-2437-8, Bratislava, Slovakia

ETSI TS 101 270-1 (1999). VDSL, Part 1 - Functional requirements, (October 1999)

ETSI TS 101 270-2 (2001). VDSL, Part 2 - Transceiver specification, (February 2001)

ETSI TS 101 475 (2000). Broadband Radio Access Networks (BRAN), HIPERLAN Type 2, Physical (PHY) Layer, Technical Specification, (April 2000)

ETSI TS 101 761-1 (2001). Broadband Radio Access Networks (BRAN), HIPERLAN Type 2, Data Link Control (DLC) Layer, Part 1: Basic Data Transport Functions, (December 2001)

Ferreira, H.C.; Lampe, L.; Newbury, J.; Swart, T.G. (2010). *Power Line Communications*, John Wiley & Sons, ISBN 978-0-470-74030-9, Chichester, United Kingdom

Götz, M.; Rapp, M.; Dostert, K. (2004). Power Line Channel Characteristics and Their Effect on Communication System Design. *IEEE Communications Magazine*, Vol.42, No.4, (April 2004), pp. 78-86, ISSN 0163-6804

Held, G. (2006). *Understanding Broadband over Power Line*, Auerbach Publications, ISBN 0-8493-9846-0, Boca Raton, United States of America

Hrasnica, H.; Haidine, A.; Lehnert, R. (2004). *Broadband Powerline Communications Networks*, John Wiley & Sons, ISBN 0-470-85741-2, Chichester, United Kingdom

Cherubini, G. et al. (2000). Filter Bank Modulation Techniques for Very High-Speed Digital Subscriber Lines. *IEEE Communication Magazine*, Vol.38, No.5, (May 2000), pp. 98-104, ISSN 0163-6804

Kaminow, I.P.; Li, T.; Willner, A.E. (2008). *Optical Fiber Telecommunications V B: Systems and Networks*, Elsevier Inc., ISBN 978-0-12-374172-1, San Diego, United States of America

Mukherjee, B. (2006). *Optical WDM Networks*, Springer Science+Business Media Inc., ISBN 978-0387-29055-3, New York, United States of America

Mestagh, D. et al. (2000). Zipper VDSL –A Solution for Robust Duplex Communication over Telephone Lines. *IEEE Communications Magazine*, Vol.38, No.5, (May 2000), pp. 90-96, ISSN 0163-6804

Oksman, V.; Werner J.-J. (2000). Single-Carrier Modulation Technology for Very High-Speed Digital Subscriber Line. *IEEE Communications Magazine*, Vol.38, No.5, (May 2000), pp. 82-89, ISSN 0163-6804

Róka, R. (2002). Theoretical and practical limits of transmission channels used by the ADSL technology in the metallic lines environment in the access network in Slovakia. *Journal of Electrical Engineering - EČ*, Vol. 53, No. 3-4, (March 2002), pp. 91-96, ISSN 1335-3632

Róka, R.; Cisár, R. (2002). The Analysis of Negative Influences in the Environment of Homogeneous Symmetric Lines at the Signal Transmission by Means of the ADSL

Technology. *Journal of Electrical Engineering - EČ*, Vol.53, No.9-10, (September 2002), pp. 241-249, ISSN 1335-3632

Róka, R. (2004). Environmental Influences on the Power Spectral Densities of VDSL Signals. *Journal of Electrical Engineering – EČ*, Vol.55, No.1-2, (January 2004), pp. 18-24, ISSN 1335-3632

Róka, R.; Dlháň, S. (2005). Modeling of transmission channels over the low-voltage power distribution network. *Journal of Electrical Engineering – EČ*, Vol. 56, No. 9-10, (September 2005), pp. 237-245, ISSN 1335-3632

Róka, R.; Urminský, J. (2008). Experimental Measurements for Verification of the Parametric Model for Reference Channels in the Real PLC Environment. *Journal of Electrical Engineering – EČ*, Vol. 59, No. 3, (May 2008), pp. 146-152, ISSN 1335-3632

Róka, R. (2009). Modeling of Environmental Influences at the Signal Transmission by means of the VDSL and PLC Technologies. *International Journal of Electrical Communication Networks and Information Security – IJCNIS*, Vol. 1, No. 1, (April 2009), pp. 6-13, ISSN 2073-607X

Schiff, M. (2006). *Introduction to Communication Systems Simulation*, Artech House Inc., ISBN 1-59693-002-0, Norwood, United States of America

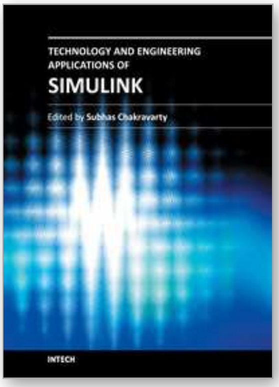
Shieh, W.; Djordjevic, I. (2010). *OFDM for Optical Communications*, Elsevier Inc., ISBN 978-0-12-374879-9, San Diego, United States of America

Werner, J. J. (1991). The HDSL Environment. *IEEE Journal on Selected Areas in Communications*, Vol.SAC-9, No.6, (August 1991), pp. 785-800, ISSN 0733-8716

Xiong, F. (2000). *Digital Modulation Techniques*, Artech House Inc., ISBN 0-89006-970-0, Norwood, United States of America

Zimmermann, M.; Dostert, K. (2002a). Analysis and Modeling of Impulsive Noise in Broadband Powerline Communications. *IEEE Transactions on Electromagnetic Compatibility*, Vol.44, No.1, (February 2002), pp. 249 – 258, ISSN 0018-9375

Zimmermann, M.; Dostert, K. (2002b). Multipath Model for the Powerline Channel. *IEEE Transactions on Communications*, Vol.50, No.4, (April 2002), pp. 553-559, ISSN 0090-6778



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